Direct photons in ATLAS@LHC

Mark D. Baker[1], Jiangyong Jia[1,2], and Peter Steinberg[1]
for the ATLAS Collaboration*
[1] *Physics Department, Brookhaven National Laboratory*
[2] *Chemistry Department, State University of New York, Stony Brook*

The ATLAS detector at the LHC is capable of efficiently separating photons and neutral hadrons based on their shower shapes over a wide range in η, ϕ, and E_T, either in addition to or instead of isolation cuts. This provides ATLAS with a unique strength for direct photon and γ-jet physics ("tomography") as well as access to the unique capability to measure non-isolated photons from fragmentation or from the medium. We present a first look at the ATLAS direct photon measurement capabilities in p+p and Pb+Pb collisions at LHC energies over the region $|\eta| < 2.4$.

I. INTRODUCTION

Direct photons are produced during the initial creation and evolution of the system and can be divided into prompt photons produced in hard processes in the initial collision, and non-prompt photons produced by jet fragmentation, in-medium gluon conversion and medium-induced bremsstrahlung. Prompt processes such as $q + g \to q + \gamma$ and $q + \bar{q} \to g + \gamma$ lead to final states with a high p_T parton (gluon or quark) balanced by a prompt photon with roughly comparable p_T [1]. In other words, they provide *a calibrated parton* inside of the medium, allowing a direct, quantitative measurement of the energy loss of partons in the medium and of the medium response.

ATLAS has a unique capability to study such processes because of the large-acceptance calorimeter with longitudinal and fine-transverse segmentation [2]. In particular the first main layer of the calorimeter is read out in narrow transverse strips. This segmentation allows us to purify our sample of γ-jet events by rejecting jet+jet background. It further allows us to identify photons which are near or even inside of a jet, where isolation cuts cannot be used. This provides access to non-prompt photons from jet fragmentation, from in-medium gluon conversion and from the medium-induced bremsstrahlung.

II. TECHNIQUE

The design of the ATLAS electromagnetic calorimeter is optimal for direct photon identification. The first layer of the electromagnetic calorimeter, which covers the full azimuth and $|\eta| < 2.4$, has very fine segmentation along the η direction (ranging from 0.003 to 0.006 units). This layer provides detailed information on the shower shape, which allows a direct separation of photons, π^0's, and η's on a particle-by-particle level. Deposited energy distributions for a typical single γ, single π^0, and single η meson are shown in the upper panels of Fig. 1. Characteristically different shower profiles are seen. The energy of a single photon is concentrated across a few strips, with a single maximum in the center, while the showers for $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ are distributed across more strips, often with two or more peaks. The broad shower profile for π^0 and η reflects the overlap of showers for two or more decay photons. Even when the two peaks are not resolved, the multi-photon showers

*Electronic address: `Mark.Baker@bnl.gov`

are measurably broader on a statistical basis. The lower panels of Fig. 1 show the strip layer energy distributions surrounding the direction of single particles embedded in central Pb+Pb events. The γ, π^0 and η in these panels are the same ones used in the upper panels. Despite the huge number of low-energy particles produced in Pb+Pb events, the shower shape for the embedded particle is almost unchanged by the background. Thus the strip layer allows the rejection of π^0 and η decay photons over a very broad energy range, and the performance for the background rejection and identification efficiency should not depend strongly on the event centrality.

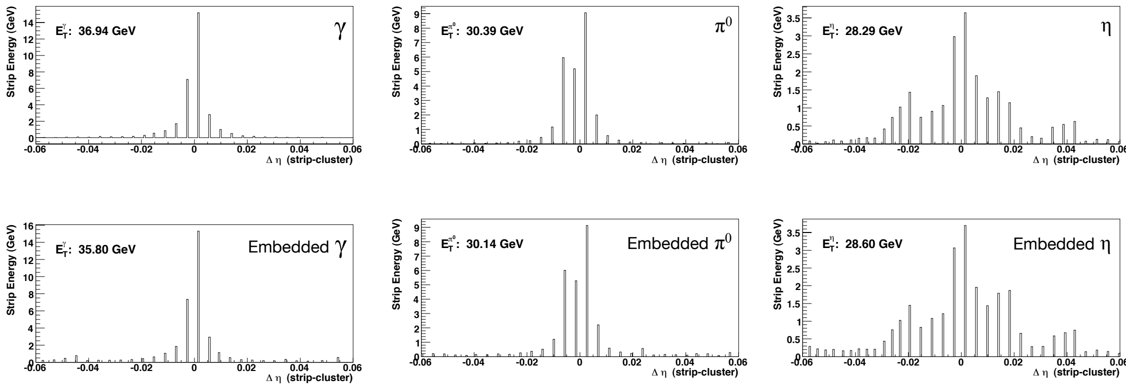

FIG. 1: The energy deposition in the strip layers around the direction of (upper left) a single photon, (upper middle) a single π^0 and (upper right) a single η as well as for (lower panels) the identical particles embedded in a central ($b = 2$ fm, $dN_{ch}/d\eta = 2700$) Pb+Pb event. Reconstructed E_T values are indicated.

III. RESULTS

To distinguish direct photons from neutral hadrons, cuts have been developed based on the shower shape in the strip layer. These cuts reject those showers that are anomalously wide or exhibit a double peak around the maximum. In general, better rejection can be achieved using a tighter cut, but at the expense of reduced efficiencies. The performance has been quantified via photon efficiency (ϵ_γ) and relative rejection ($R_{\mathrm{rel}} \equiv \epsilon_\gamma/\epsilon_{\mathrm{hadron}}$). The relative rejection basically reflects the gain in the signal (direct photon yield) relative to background (neutral hadron yield).

In this analysis, two sets of cuts have been developed, a "loose" cutset and a "tight" cutset. The performance for these two sets is summarized in Fig. 2. The loose cuts (upper panels) yield a factor of 1.5–3 relative rejection with a photon efficiency of about 90%; the tight cuts (lower panels) yield a factor of 3–5 relative rejection with an efficiency of about 50%.

In addition to the photon identification cuts, isolation cuts have been developed which, on their own, provide relative rejection factors of 7–10 for $E_T > 50$ GeV. These isolation cuts cannot be used to study non-isolated photons, but in the case of γ-jet, they can be combined with the photon identification cuts to significantly reduce the background from jet-jet events. Figure 3 shows the simulated spectra of jets (open circles), $\pi^0+\eta$ (solid squares), $\pi^0+\eta$ passing the cuts (solid circles), expected γ (solid line), and expected γ passing the cuts (dashed line). As the figure shows, above about 60 GeV, the cuts suppress the yield of background neutral hadrons below the direct photon yield.

The direct photon performance is summarized in Fig. 4. The signal-to-background ratio is the best in p+p collisions, which is about factor of 4–5 larger than that for most central Pb+Pb events. However, by taking into account the benefit one gains from the likely hadron suppression,

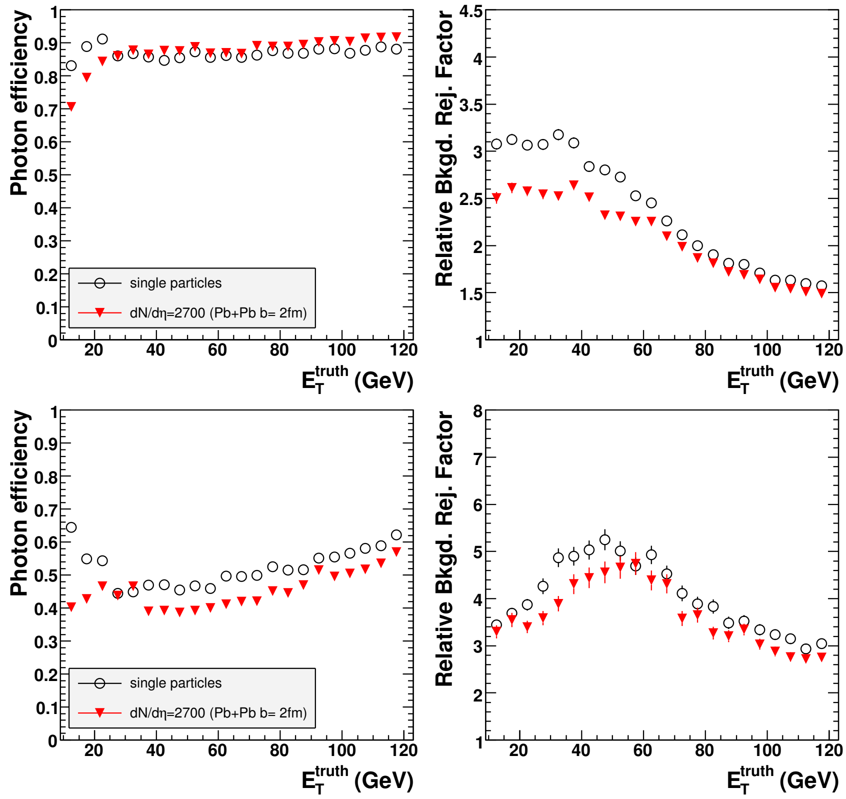

FIG. 2: (upper panels) Photon identification efficiency and relative rejection factor (averaged over $|\eta| < 2.4$) for neutral hadrons for the loose cutset for p+p (open circles) and central ($b = 2$ fm, $dN/d\eta = 2700$) Pb+Pb collisions (filled triangles). (lower panels) As above but for the tight cutset. Note the change in scale between the upper and lower right-hand panels.

we expect to achieve a similar level of performance that is approximately independent of the event centrality.

IV. CONCLUSIONS

This writeup has presented the ATLAS performance for direct photon identification. The first layer of the ATLAS EM calorimeter provides an unbiased relative rejection factor of either 1.5–3 (loose shower shape cuts) or 3–6 (tight shower shape cuts) for neutral hadrons. The loose γ identification cuts can be combined with isolation cuts, resulting in a total relative rejection of about 20, even in central Pb+Pb collisions, providing a relatively pure sample of calibrated partons interacting with the medium. The expected luminosity per LHC Pb+Pb year will provide 200k photons above 30 GeV, and 10k above 70 GeV per LHC year.

The tight shower shape cuts alone provide sufficient rejection against hadron decays within jets to allow the study of fragmentation photons, in-medium gluon conversion and medium-induced bremsstrahlung. This is a unique capability of ATLAS.

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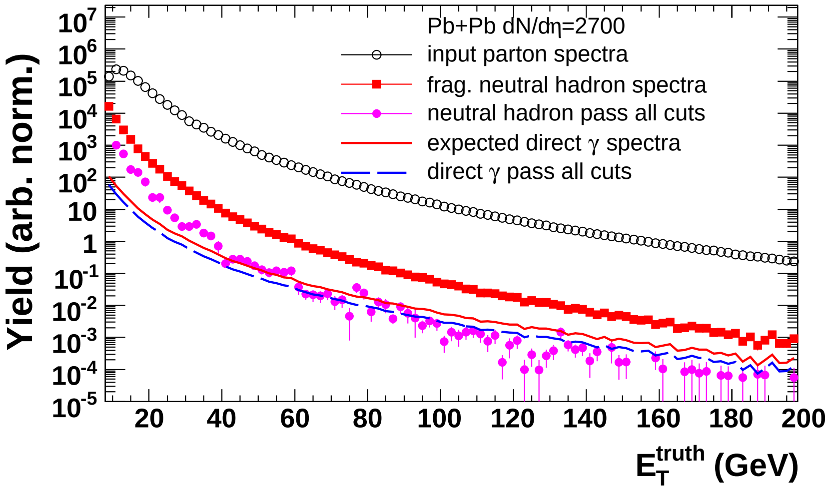

FIG. 3: The performance of the shower shape cuts and isolation cuts on PYTHIA di-jets embedded into $b = 2$ fm Pb+Pb events. The spectra shown are for input jets (open circles), input $\pi^0 + \eta$ (solid square), remaining $\pi^0 + \eta$ (solid circles), expected direct γ (solid line) and remaining direct γ (dashed line).

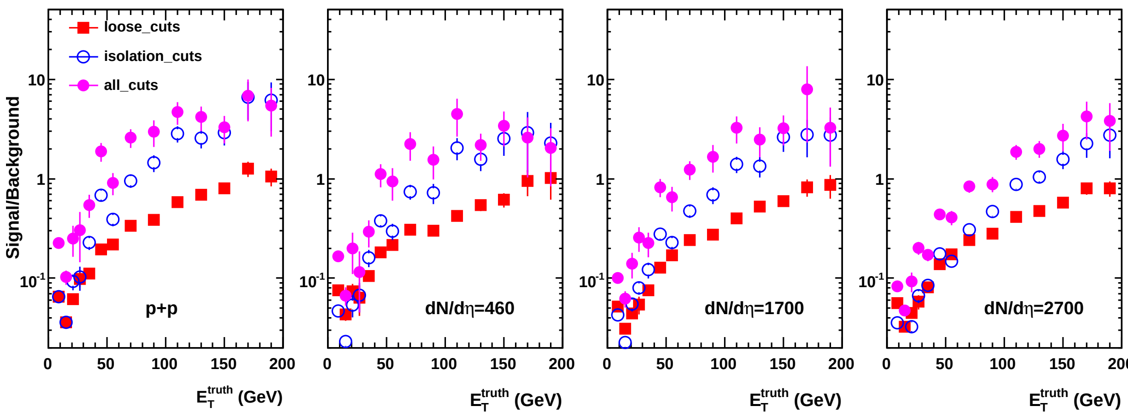

FIG. 4: The ratio of direct photons over background neutral hadrons passing the loose shower shape cuts only (solid squares), isolation cuts only (open circles) and combined cuts (solid circles) for different occupancies under the assumption that $R_{\mathrm{AA}} = 1$ for all centralities.

References

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